(12) UK Patent Application (19) GB (11) 2 034 435 A

(21) Application No 7936016
(22) Date of filing 17 Oct 1979
(30) Priority data
(31) 78/41738
(32) 24 Oct 1978
(33) United Kingdom (GB)
(43) Application published 4 Jun 1980
(51) INT CL³ F15D 1/06
(52) Domestic classification F2R
(56) Documents cited GB 1502000 GB 307762
(58) Field of search B7V F1C F1T F2R

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(54) Fluid rotary power conversion means

(57) The power conversion means comprises a boundary structure 2 within which at least one energy exchanging rotor having blades 4 is rotatably mounted, the boundary structure extending downstream of the blades substantially in an axial direction and having at least one circumferential discontinuity 1 adjacent the blades and being at least partly curved in cross-section. The discontinuity 1 is arranged to receive the fluid vorticity generated by rotation of the blades 4 such that a standing ring vortex 3 is maintained at the discontinuity and has an axial extent which is less than the width of the path swept by the blades. The invention has particular application to compressors or fans and aircraft or marine propellers.

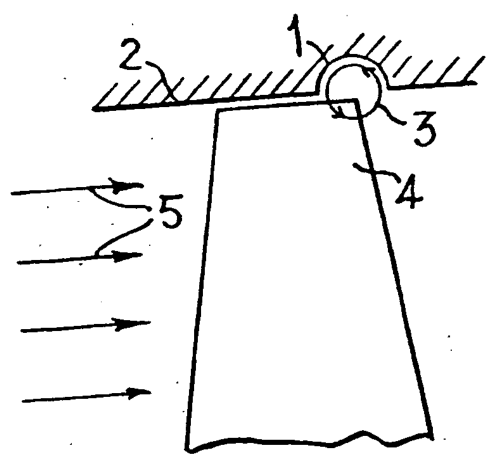

Fig.7

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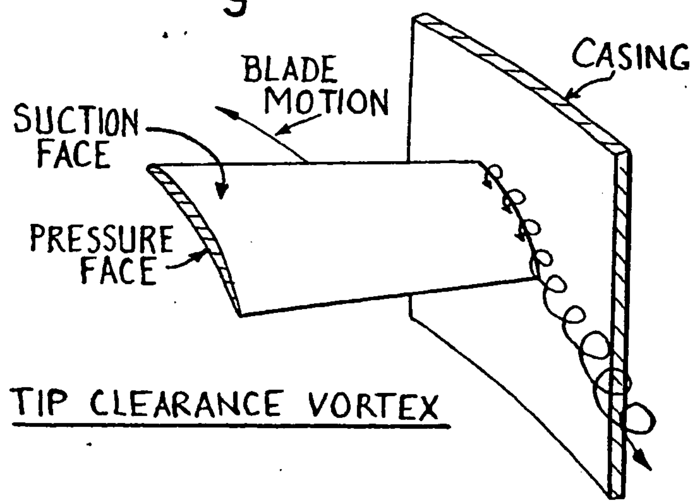
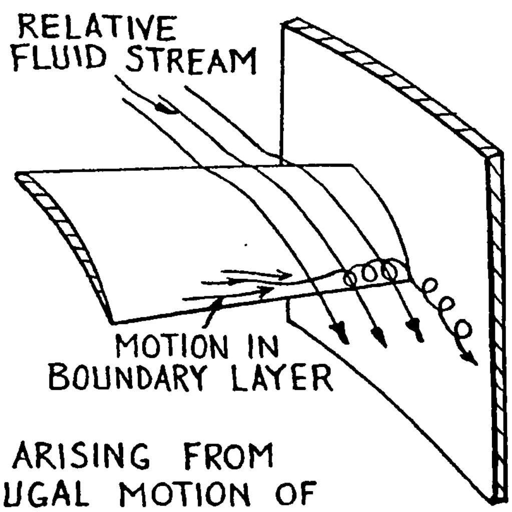
Fig.1



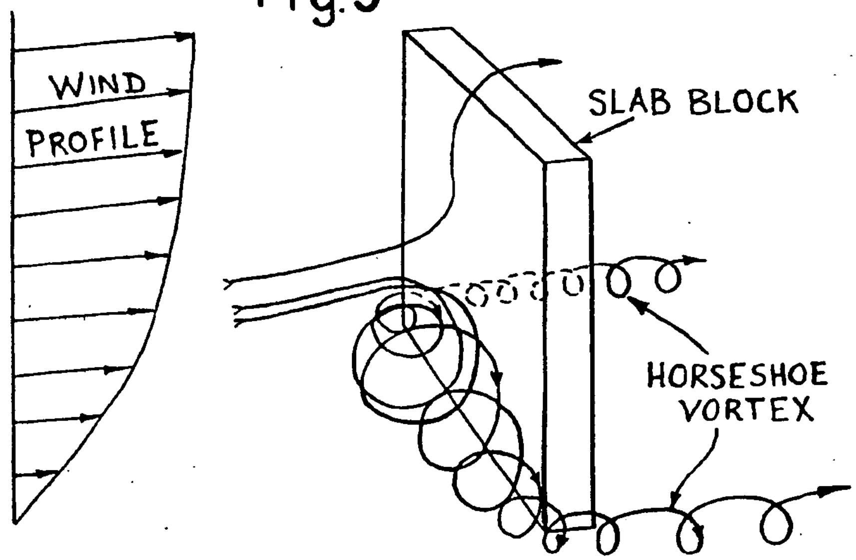
TIP CLEARANCE VORTEX



VORTEX ARISING FROM CENTRIFUGAL MOTION OF BLADE BOUNDARY LAYER

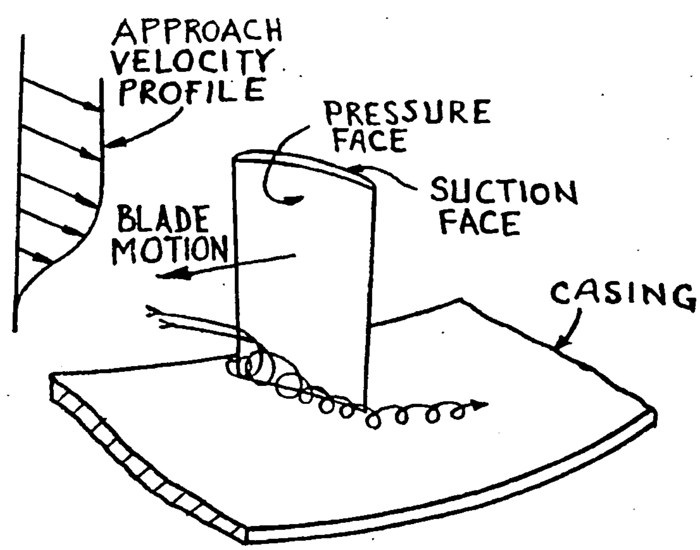
Fig.2

Fig.3



HORSESHOE VORTEX AT BASE OF SLAB BLOCK DUE TO WIND VELOCITY PROFILE

Fig.3a



VORTEX SHED FROM PRESSURE FACE IN PRESENCE OF CASING BOUNDARY LAYER

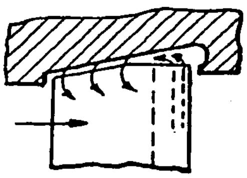


Fig.4

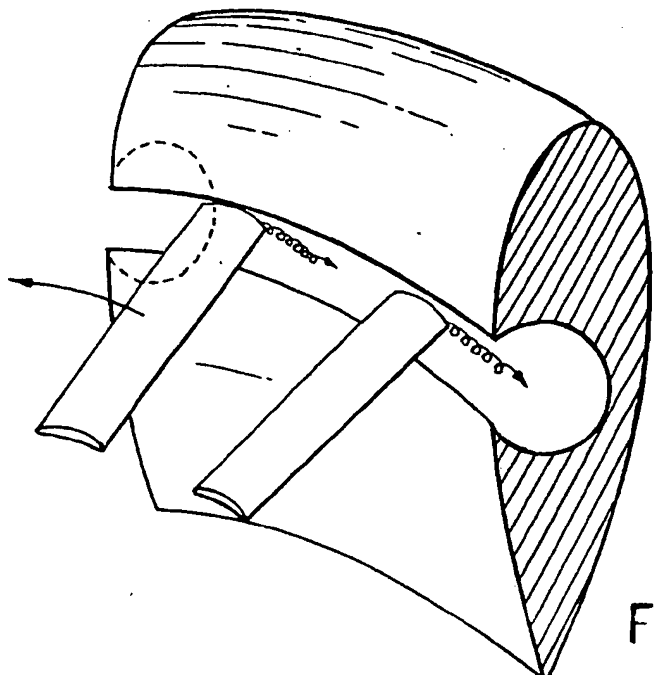


Fig.5

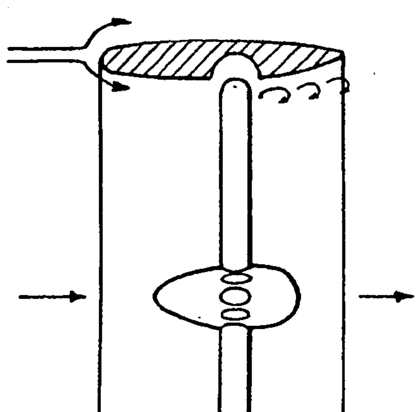


Fig.6

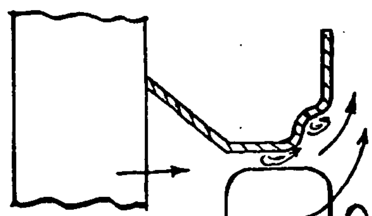


Fig.6a

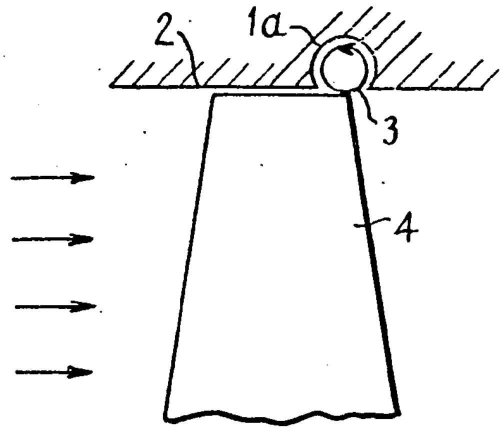


Fig.7a

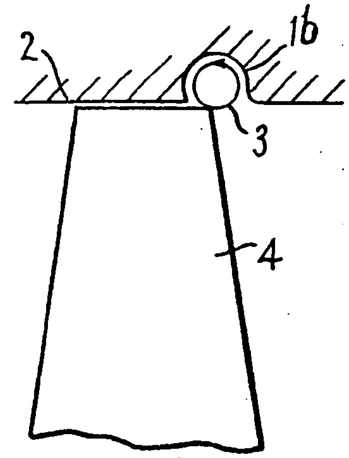


Fig.7b

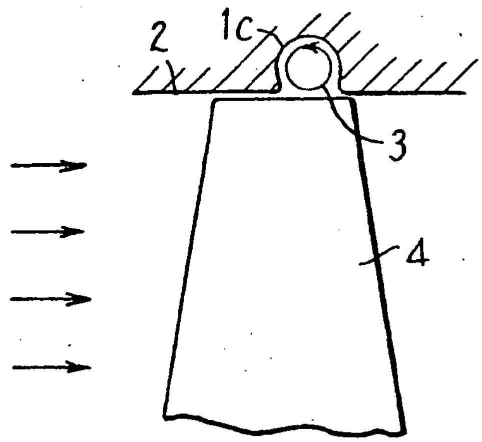


Fig.7c

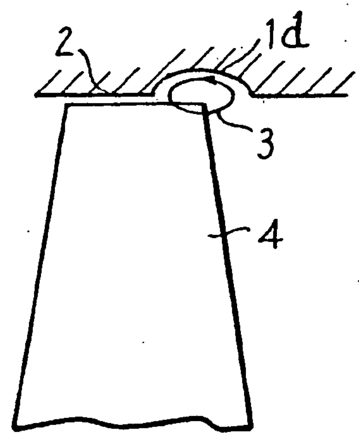


Fig.7d

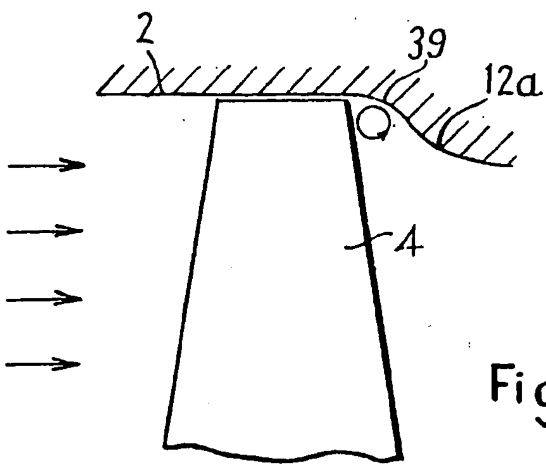


Fig.11a

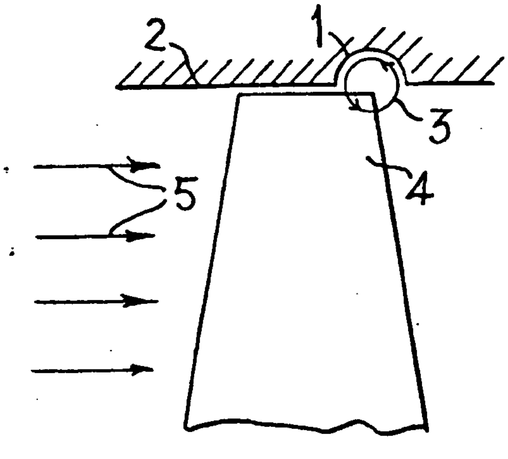


Fig.7

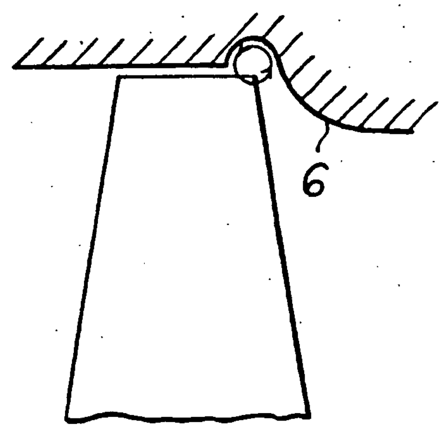


Fig.8

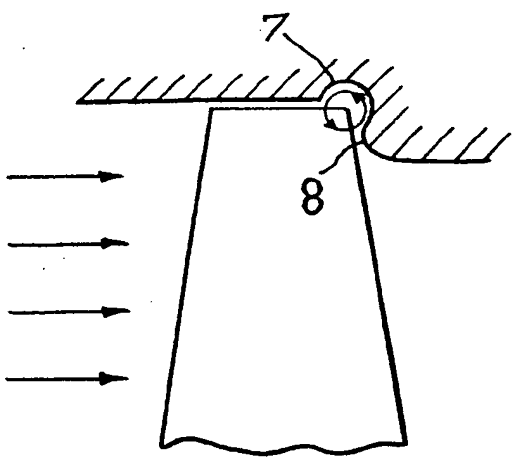


Fig.9

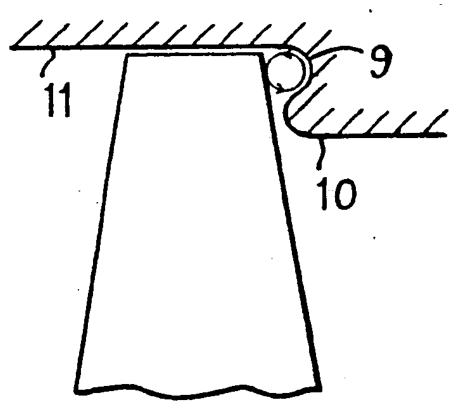


Fig.10

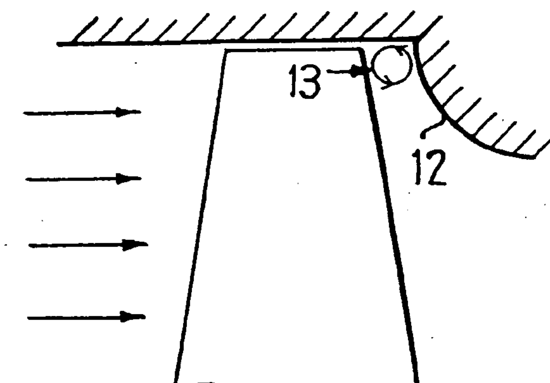


Fig.11

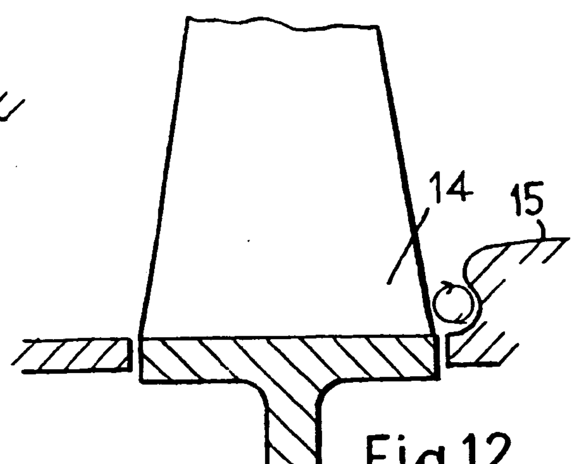


Fig.12

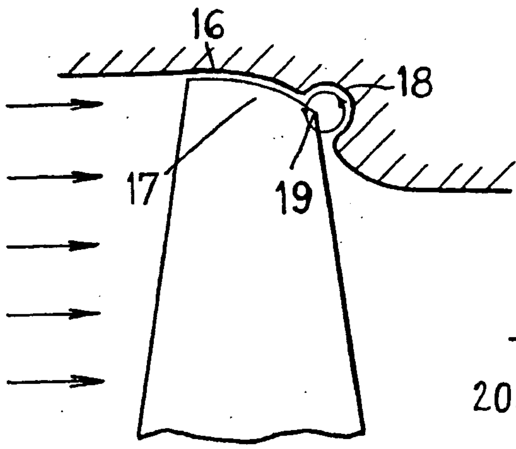


Fig.13

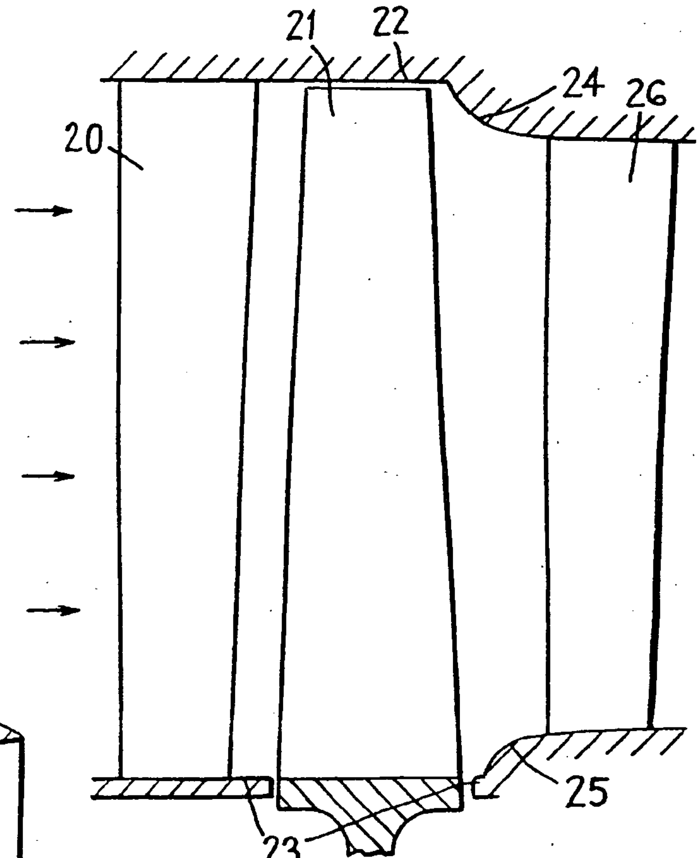


Fig.14

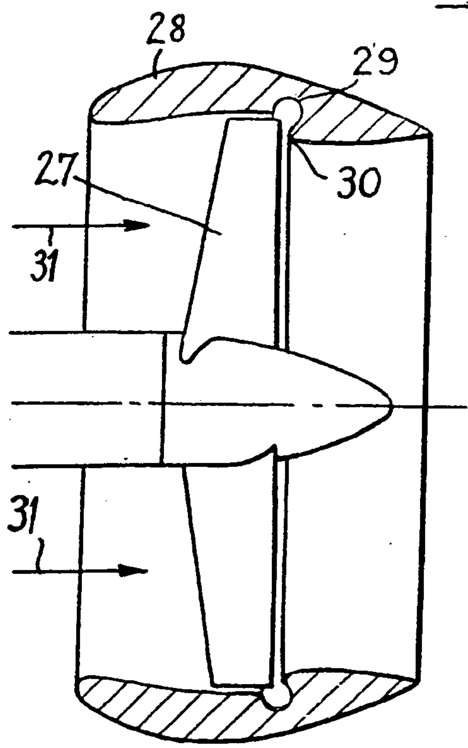


Fig.15

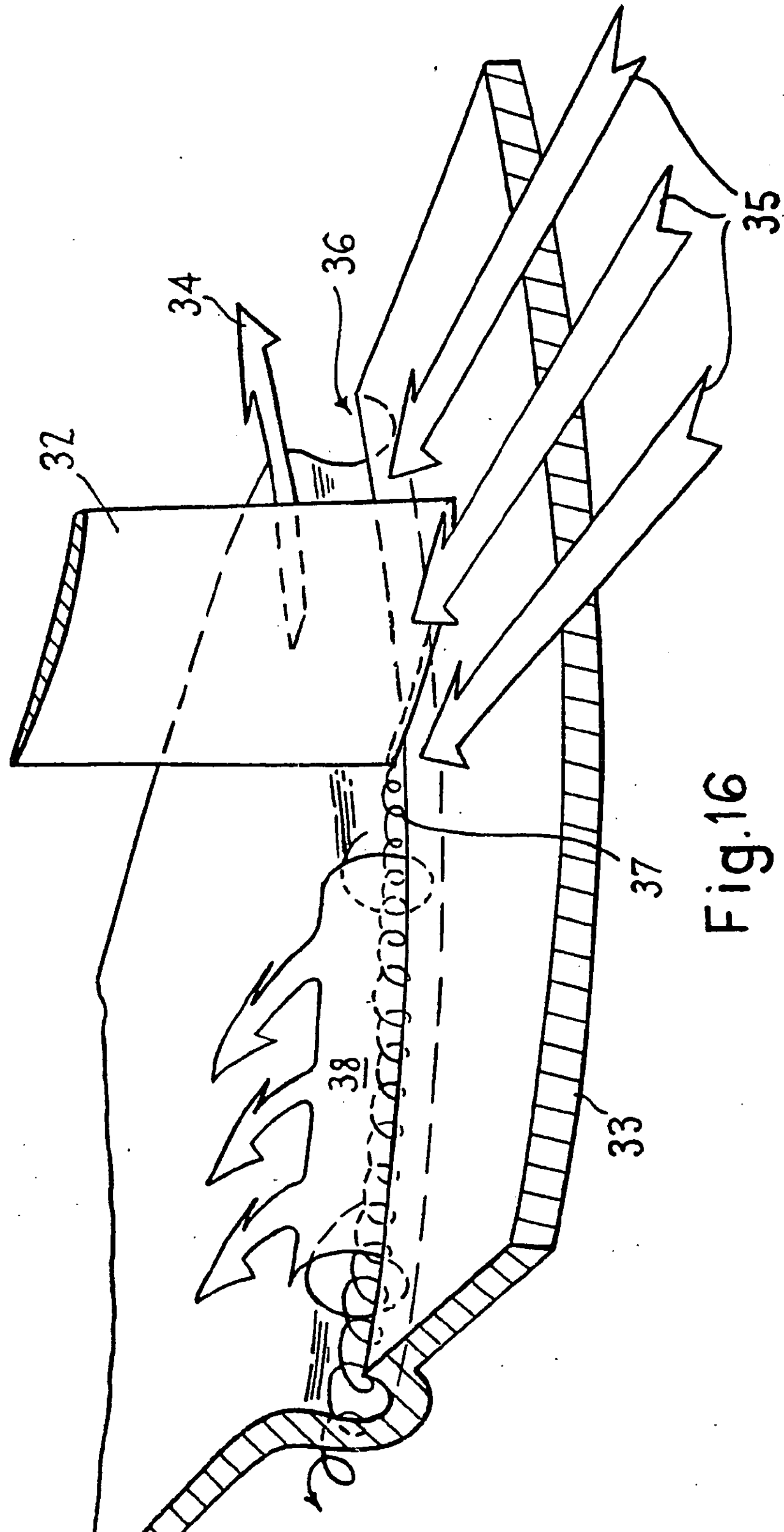


Fig.16

SPECIFICATION

Fluid medium rotary power conversion means

This invention relates to rotary power conversion means and systems, such as axial and centrifugal flow compressors, axial flow fans, ducted marine and aircraft type propellers, fluid impellers and other fluid compressing and/or accelerating means, hereafter all referred to as rotary power conversion means. The invention is concerned with fluid flow problems arising in the zone of interaction between a moving row of rotor blades and adjacent fixed casing or other like boundary structure, and is chiefly though not exclusively applicable to axial flow types of device.

One class of problem is related to the clearance between the tips of the blades and the boundary structure. A usual requirement for the efficient operation of power conversion means is that the said tip clearance should be small. A substantial clearance can lead to unwanted recirculation of the flow at the tips of rotor blades, excessive shedding of vortices, partial detachment of the flow aft of the plane of the rotor from the boundary structure, and other effects which may be deleterious to the operation of the rotary power conversion means.

Many attempts have been proposed or made to improve the performance of axial flow fans and compressors, shrouded propellers and like power conversion means by attempting to seal or otherwise deal with the clearance between the moving blade tips and the fixed casing or shroud. These include adopting, from turbine practice, the tip ring with labyrinth seal behind it, which gives too much windage loss in fans and compressors, etc, to be of real value, to raising a small flange immediately behind the trailing edge of the blade tips, which tends to give flow separation down the inside of the casing, and to eliminating clearance by arranging for rubbing contact between the blade tips and the casing wall which has been achieved in experimental conditions only. The most effective and most widely adopted partial solution is the use of a very fine tip clearance, but this almost always introduces enginerring problems and, where marine propellers are involved, high cavitation erosion as well.

To avoid these fine clearance problems a wide toroidal cut-out in the casing wall opposite the blade tips has been proposed, thus relieving the engineering limitations as regards clearance but at the same time allowing the tip vortex to develop fully. The large size of the cut-out can introduce engineering problems of its own while the large quantities of fluid spilled at the tips with the loss of effective blade aspect ratio and relaxation of tip loading are all factors which are better avoided in many cases.

Other approaches to the problems are the various 'casing treatments' consisting of radial, circumferential, skew or other slots set in the casing wall in line with the blade tips. In some circumstances these may have a beneficial effect on performance, raising efficiency, improving stall characteristics and increasing the pressure coefficient.

As distint from means of the aforesaid nature whereby the attempt is made to limit tip effects by the use of some kind of solid construction or fine clearance or combination of such means, the present invention uses fluid dynamic means to modify the effect of the clearance, with the object inter alia of improving the performance, easing requirements for fine clearance and minimising or controlling cavitation effects when used in water.

The basis of the present proposals is the stabilisation of the flow leaving the blade tip and/or root by contriving to maintain a small standing ring vortex in the vicinity of the blade tip and/or root trailing edge where analogous conditions also occur. In general the flow trapped, cast, slung or induced into this vortex is given an opportunity to settle into an orderly motion before the outer layers peel off, at least partially, pass as a sheet down the wall of the boundary structure or interacts with the vorticity generated by the succeeding blade.

A device according to the invention is designed to provide a local form to the boundary structure in the vicinity of an energy exchaning rotor such that a full, or partial, and largely stable ring vortex is formed in such a position that it occupies a space between the relevant part of the rotor and the local boundary structure. The device may be so formed that if exposed to a fluid stream in the absence of an energy exchanging rotor it generates, of its own accord, a standing ring vortex turning in the same direction as a rotor generated vortex, for example a tip vortex, or it may simply trap the rotor vortices. In each case the rotation in the ring vortex is in the direction that encourages the passage of fluid within the annulus, disc or other passage it encloses or bounds.

Accordingly the present invention consists in fluid medium rotary power conversion means comprising a boundary structure within which at least one energy exchanging rotor is rotatably mounted, the energy exchanging rotor having a plurality of blades and the boundary structure extending downstream of the blades substantially in an axial direction and having at least one circumferential discontinuity adjacent the blades, at least a part of the said discontinuity being of curved configuration when considered in cross-section and the said discontinuity being arranged to receive fluid vorticity generated by rotation of the blades within the boundary structure such that a standing ring vortex is maintained at the discontinuity and has an axial extent which is less than the width of the path swept by the blades.

Preferably, at least some of the fluid in the standing ring vortex is shed from the discontinuity in the form of a sheet.

The discontinuity may be in either or both of the inner and outer walls of the boundary structure, e.g. adjacent the blade trailing edges at either or both the tip and root of the blades.

The discontinuity may take a number of forms, e.g. a circumferential generally semi-circular recess in the wall of the boundary structure; a part-circular recess coupled with a shoulder including a faired lip which extends into the fluid flow downstream of the blade trailing edge; a lip or shoulder extending into the fluid flow with the recess formed in or by the

same, or a faired shoulder extending into the fluid flow with a space between the blade trailing edges and the shoulder in which the standing ring vortex can develop.

The rotary power conversion means can comprise, axial and centrifugal flow compressors, e.g. for gas turbine engines, shrouded and unshrouded axial flow fans for both gas turbines engines and ventilators and shrouded and unshrouded propellers for both marine and aeronautical applications.

In order that the invention may be more readily understood reference will now be made to the accompanying drawings, in which:

Figures 1, 2, 3 and 3a illustrate the vortices shed by a rotor blade in the presence of a boundary structure,

Figures 4, 5, 6 and 6a illustrate four different forms of previously proposed rotary power conversion means having discontinuities in the boundary structure,

Figure 7, 7a to 7d, 8 to 11, 11a and 12 to 15 illustrate, diagrammatically, various embodiments of the present invention, and

Figure 16, illustrates some aspects of the fluid flow in one form of discontinuity, in accordance with the present invention.

Referring to figures 1, 2, 3 and 3a, the vorticity shed at and near a blade tip moving in close proximity to a casing wall is made up not of one but of several components. One of these corresponds to the classicial wing tip vortex as modified by the presence of the wall and disappears when rubbing contact or other complete sealing is achieved. This is sometimes supposed to be the only source of vorticity and losses at the tip. Other sources of tip vorticity are not eliminated by any form of sealing. On the blade, any fluid which slows up significantly in the boundary layer is subject to centrifugal forces and tends to move radially outwards along the blade. The effect is most strongly found on the suction surface where the fluid tends to accumulate along the trailing edge and moves towards the tip in a thickening layer. Towards the tip it can form into the beginnings of a separation vortex and it can play a large part in the development of tip stalling. This fluid leaves the blade tip as a rotating vortex having the same direction of rotation as the previous one, with which it normally interacts, and then trails downstream close to the casing wall on a helical path.

These two vortices are illustrated in Figures 1 and 2. It may be noted that the direction of rotation of these vortices are the opposite to that required from 'vortex generators' which are sometimes used to re-energise a tired boundary layer. The present vortices tend to bring the fluid on the casing wall to rest and to give up their excess energy to the main stream, thus exaggerating rather than repressing the casing boundary layer.

A third vortex arises where the blade interacts with the casing boundary layer, or its equivalent however it is caused. The origin of this vortex is the same as that found at the foot of a tall 'slab block' building in the wind or a pile on a river bed. In these cases the faster moving fluid drives down the face of the obstruction to displace the less energetic fluid of the boundary layer at its foot. With a symmetrical rectangular building this downflow is shed as a horseshoe vortex from the base of the building, as shown in Figure 3. When the face of the building is inclined to the flow the limbs of the vortex become of unequal strength. With a fan or compressor blade the same phenomenon occurs. In this case almost all the fluid shed in this way is concentrated in the limb shed at the trailing edge of the pressure face, with little finding its way forward and round the leading edge and then downstream over the suction face at the tip. The motion of the fluid in this vortex is supported by centrifugal action, which action also tends to throw the boundary layer on pressure face (thin though it may be) into the same general movement. The rotation of this vortex where it is shed from the trailing edge of the pressure face is in the opposite direction to those previously described, while that which passes round the leading edge is in the same direction (Figure 3a).

The strength of this vortex is closely related to the thickness of the boundary layer and the extent of its manifestation is dependent upon tip clearance. When this latter is of significant size in relation to the size of the vortex all the fluid which would form the vortex can pass beneath the tip and no observable vortex appears.

A further factor related to tip flow concerned with casing boundary layer is that this latter can cause premature or even permanent tip stalling, which adds to the complexity of the flow pattern. In cases where there is come kind of tip stalling or local flow detachment taking place, a good deal of vorticity may be shed ahead of the trailing edge and the position of this shedding may influence the optimum location for the development of a standing ring vortex for the purposes of the present invention.

Referring to Figure 4, which illustrates an arrangement disclosed in US Patent No. 3011762, a row of turbine blades is rotatable in a casing in which a groove is formed. The axial length of the groove is greater than the span of the blade path and has an annular recess adjacent the trailing edges of the blades. It should be noted that in distinction to the present invention, this arrangement is concerned with turbine blades and associated casings, e.g. an expanding and decelerating fluid flow in which the vortices and flow patterns in the region of the blade tips and roots differ considerably from those of the rotary power conversion means of the present invention.

The function of the arrangement in Figure 4 is so that the annular recess receives cooling air ejected radially from the rear portion of the turbine blade, this air then being forced into the spaces between the blades and the groove, thereby tending to prevent any leakage of the main gas flow between the blades and the groove, and the spaces between adjacent blades.

Thus, the cooling air is used to prevent leakage of the main gas flow between the blades and the turbine casing, the cooling air being conveyed in an upstream direction so that it is possible to recuperate in the form of expansion work, most of the work spent in compressing the air that has been used both

to prevent gas leaks and to cool the blades themselves.

Referring to Figure 5, this shows a shrouded propeller as disclosed in US Patent No. 3620640 in which the shroud has a very large torroidal recess. The tips of the propeller blades rotate in the recess and the object of the arrangement is to solve the tip clearance problem by eliminating all the casing in the region of the blade tips. The size of the recess allows a large quantity of air to be entrained, amounting effectively to a fully developed tip vortex. This arrangement reduces the effective aspect ratio of the blade when compared to an orthodox shroud; will probably reduce the bound vorticity round the shroud induced by the propeller action and so reduce shroud thrust, and will exaggerate the non-uniform velocity profile near the blade tip.

Referring to Figure 6, this also shows a shrouded propeller having a recess in the shroud adjacent the blade tips and comprises one arrangement disclosed in US Patent No. 3934410. The proposed object of this arrangement is to capture the blade tip vortex and allow it to travel slowly downstream expanding the propeller slip-stream so that the average exit velocity is reduced. This device has similarities with that shown in Figure 5, except that the blade tips do not actually travel in the recess and the recess appears to have a larger curvature.

Referring to Figure 6*a*, an arrangement claiming to utilize the coanda effect in connection with a short and highly curved shroud is disclosed in US Patent No. 4,061,188. This arrangement which has a large tip clearance proposes to make use of low pressure vortices to maintain flow attachment to the casing wall in strongly divergent flow conditions. Such an arrangement would be unsuitable for high performance machinery due to the excessive tip clearance and the unlikelihood of obtaining stable vortex conditions.

The description and function of embodiments of the present invention as illustrated in Figures 7 to 16 will serve to distinguish clearly the present invention from the prior proposals.

Figure 7 shows in cross-section in the direction of flow, a semi-circular circumferentially extending discontinuity in the form of a recess 1 in a boundary structure or casing 2. The recess locates a ring vortex 3 above the trailing edge of a rotor blade tip 4 and the recess is located adjacent the blade trailing edge and extends over only a portion of the blade trailing edge, i.e. discontinuity is located in the region of the trailing edge of the blade. The general direction of the fluid flow is shown by arrows 5. The precise fore and aft relationship between the blade tip and the recess is not defined by the figure.

Figure 7*a* shows a part-circular recess 1*a* having a buried periperhy greater than that of a semi-circle. Figure 7*b* shows a similar recess 1*b* having a downstream edge smoothly faired into the line of the boundary structure. Figure 7*c* shows a recess 1*c* located ahead of the blade trailing edge with both upstream and downstream edges of the recess smoothly faired and Figure 7*d* shows a semi-elliptical recess 1*d*.

The indication of the location of the vortex in these and in subsequent Figures is indicative only and does not define its interaction with the blade flow.

Figure 8 shows a similar arrangement to Figure 7 with the addition of a shoulder 6, provided in part, to assist in locating the ring vortex 3 in the required position. The shoulder 6 extends into the fluid stream and is faired with the recess at its upstream end and with the continuing line of the casing downstream.

Figure 9 shows an arrangement similar to Figure 7 except that a recess 7 of greater arcuate length is formed by a lip 8 which extends into the fluid stream.

Figure 10 shows a ring vortex entraining recess 9 entirely housed in a shoulder 10 without breaking the original upstream line of the casing or boundary structure 2. This arrangement could be used where the shoulder 10 comprises, for example, an insert or separate structure fitted inside a casing having an uninterrupted line. In this case the discontinuity is located in the region only of the trailing edges of the blades.

Figure 11 shows an arrangement in which the discontinuity is created by a shoulder 12 which extends into the fluid stream, a small space being left between the shoulder and the blade trailing edge in which the standing ring vortex may develop. Figure 11*a* shows a similar shoulder 12*a* faired into the upstream line with a curve 39.

Figure 12 shows the arrangement of Figure 9 adapted to suit the conditions at blade root 14, where vorticity might otherwise be shed along the surface of the hub fairing 15.

Figure 13 shows an arrangement in which the line of the boundary structure 16 is curved in the region swept by the blade tip 17, the recess of discontinuity being formed in the vicinity of the path of the trailing edge of the blade tip 19.

Figure 14 shows the application of the invention to an axial flow compressor, e.g. for a gas turbine engine. A guide vane 20 is followed in the direction of flow by a rotor blade 21 the boundary structure comprising an outer casing 22 and a hub 23, each being provided with a discontinuity or shoulder 24, 25 respectively, that located the standing ring vortices (not shown) as in the previous Figure 11. A guide vane 26 of the following stage is mounted between the shoulders.

Figure 15 shows the application of the invention to a marine propeller 27 arranged in an annular duct which incorporates a discontinuity in the form of a recess 29 and a shoulder 30. Flow direction is shown by arrows 31.

Referring to Figure 16, this shows in an illustrative fashion only some of the aspects of the flow in one form of discontinuity. A blade 32 moves in a casing 33 in the direction of the arrow 34 with the working fluid approaching from the direction of the arrows 35. Two of the components of a standing ring vortex, located by the discontinuity 36 are shown in part, an expanding core 37 and an outer sheath 38 which peels off in the form of a sheet to pass downstream along the wall of the casing.

The size, form and position of the discontinuity provided for the ring vortex to develop and its position relative to the blade tip will depend on fluid

dynamic considerations relevant to a particular application and to such constraints as may be imposed by, constructional, weight or cost factors. The arrangements of Figures 7 and 11 have merits of simplicity, while very stable conditions are provided with a form such as is shown in Figure 7*a* or 8. In, for example, the applications to a power conversion means such as an axial flow compressor where the cross sectional area is reduced between stages, the form of the shoulder may be such as to provide the reduction needed and at the same time be shaped with a view to providing a suitable velocity profile for the subsequent stage. In the case of an application to a ducted marine propeller which may be subject to tip vortex cavitation, the provision for the ring vortex can be such as to ensure the enclosure of the cavitation in a sufficient sheath of uncavitated fluid so as to prevent collapse of the cavitation from taking place at the surface of the boundary structure. This provision can also be chosen in connection with the propeller loading, blade tip shape, pitch distribution and other relevant factors, to maintain as far as possible conditions in which the core of the standing ring vortex remains in a cavitated state, thus eliminating at least to some degree the effects engendered by cavitation collapse.

One aspect of the fluid dynamic action may be approximately described in the following terms. Some fluid from the pressure face of one blade is driven under the tip and trails as a vortex in the recess or other discontinuity instead of passing downstream. The vortex is then met by the next blade in the succession where it is experienced as a vortex which is tending to drive the fluid up the pressure face of this blade in oppostion to the tendency of the fluid to be driven down it. Since the strength of the vortex shed by uniform blades in a uniform stream will be the same, this opposition means that the blades will not add progressively to the total strength of the vortex, but will need only to provide enough energy to replace that lost by friction between successive blades. Thus the total energy taken by this component of the tipvortex system will only be that required to maintain the ring vortex itself, which should generally be considerably less than that lost when the tip vortices are shed separately.

At the blade roots (or at the tips in conditions of rubbing contact) where there is no radial clearance, a similar type of vortex is still shed, its origin being generally attributed to boundary layer effects. An arrangement according to the invention can be similarly applied and will function in a fashion analogous to that previously described.

A further effect of the invention when applied to multi-stage machinery is that the reduction in the vorticity shed along the boundary surface at the tip and root will lead to a more uniform velocity distribution in the flow approaching each subsequent stage.

The embodiment of Figure 14, which is partially described above, applies to a stage in an axial compressor. Alternative to the form shown in Figure 14, the discontinuity may take one of the forms illustrated in Figures 7 to 10, 11a and 13. The height of each shoulder where present and its distance from the trailing edge of the blade is chosen to be sufficient to locate and stabilise the ring vortex at the desired operating conditions. The height of a shoulder may also be related to the degree and form of reduction in cross-section area of the annulus between successive stages. The size and form of the discontinuity need not be the same at both tip and root. Moreover, the arrangement may be limited to one boundary surface only and may be applied to one or more stages. The optimum relative positions, sizes, shapes and clearance for the shoulder, recess if present, and blade tip and root can be determined by experiment.

Where difficulty might be experienced in machining or other process of manufacture in shaping the discontinuity, or for structural or other considerations, part or all of the effective boundary structure required may be fitted as a separate insert. The insert may be a complete ring, in two semi-circular pieces or in segments. It may be formed in conjunction with or incorporated with the following guide vanes.

A similar embodiment is that of an axial flow fan, where in general only one set of guide vanes, either upstream or downstream, is employed. When movable pitch blades are used in such a fan provision may be made for maintaining the desired clearance between blade and shoulder where provided by making the position of the latter adjustable. Where the pitch of the blades as a whole can be varied by some external control means, provision is made for the axial position of all or part of the shoulder to be varied at the same time. Alternatively, the alignment of the axis of rotation of the blades may be such that it minimises the change in clearance between blade and leading face of the shoulder. Yet further the change in clearance may be accepted. Also the blade tip and root shape may be modified to suit the presence of the shoulder, due consideration being given to avoiding shedding vorticity downstream of the position of the standing ring vortex. These means may be combined.

In the embodiment illustrated in Figure 15, for a marine propeller, the propeller 27 is enclosed in a duct 28 having a chord length about half of the propeller diameter, the propeller being located approximately midway down the duct. The recess 29 and shoulder 30 are positioned behind the blade tips. In order to facilitate removal of the propeller the duct may be made in two parts, the rear part being removable to allow the propeller to be withdrawn. Alternative arrangements may be chosen, depending on the proportions of the shoulder and required properties of the duct, for example an accelerating, a decelerating or a diffusing duct. The chord length of the portion of the duct ahead of the propeller may be reduced to any desired amount, and that aft determined by proportions needed for flow attachment and by the strength of the bound vorticity. Other configurations of discontinuity may be employed, including those which vary in form round the periphery to suit non-uniform flow.

Variants in the embodiments include recesses other than those of partly circular shape, e.g. partly elliptical. Recess shapes without any sharp internal

angles are preferred.

Analogous arrangements may be applied to other cases, for example, at the discharge from the impellers of centrifugal or mixed flow compressors or fans.

It will be appreciated that the invention has considerable variety in form and application and is not restricted to the embodiments and examples given.

It will be noted that in all the embodiments of the invention described with reference to the drawings at least a part of the discontinuity is of curved configuration when considered in the cross-sectional views illustrated, and the standing ring vortex has an axial extent which is less than the width of the path swept by the blades.

CLAIMS

1. Fluid medium rotary power conversion means comprising a boundary structure within which at least one energy exchanging rotor is rotatably mounted, the energy exchanging rotor having a plurality of blades and the boundary structure extending downstream of the blades substantially in an axial direction and having at least one circumferential discontinuity adjacent the blades, at least a part of the said discontinuity being of curved configuration when considered in cross-section and the said discontinuity being arranged to receive fluid vorticity generated by rotation of the blades within the boundary structure such that a standing ring vortex is maintained at the discontinuity and has an axial extent which is less than the width of the path swept by the blades.

2. Power conversion means as claimed in claim 1, characterized in that the discontinuity has a shape which results in at least some of the fluid in the standing ring vortex being shed from the discontinuity in the form of a sheet.

3. Power conversion means as claimed in claim 1 or 2, characterized in that said standing ring vortex has a diameter which is less than half the chord length of a blade.

4. Power conversion means as claimed in any one of claims 1 to 3, characterized in that said discontinuity is substantially in the region of the trailing edges of the blades.

5. Power conversion means as claimed in claim 4, characterized in that said discontinuity is located in the region only of the trailing edges of the blades.

6. Power conversion means as claimed in any one of claims 1 to 5, characterized in that the discontinuity has a shape such that in the absence of a rotor the movement of the fluid would generate a standing ring vortex at the discontinuity.

7. Power conversion means as claimed in any one of claims 1 to 6, characterized in that said discontinuity has a cross-sectional shape which varies round the boundary structure peripherhy.

8. Power conversion means as claimed in any one of claims 1 to 7, characterized in that the discontinuity is in the form of a recess in a wall of the boundary structure.

9. Power conversion means as claimed in any one of claims 1 to 7, characterized in that the discontinuity includes a lip or shoulder projecting into the path of fluid flow downstream of the trailing edges of the blades.

10. Power conversion means as claimed in claim 9, characterized in that the leading edge of said lip or shoulder has a recess therein.

11. Power conversion means as claimed in any one of claims 1 to 7, characterized in that the discontinuity includes a recess in a wall of the boundary structure and a shoulder projecting into the path of fluid flow flow downstream of the trailing edges of the blades.

12. Power conversion means as claimed in any one of claims 1 to 11, characterized in that the discontinuity is adjacent the blade tips.

13. Power conversion means as claimed in any one of claims 1 to 11, characterized in that the discontinuity is adjacent the blade roots.

14. Power conversion means as claimed in any one of claims 1 to 13, characterized in that the fluid is a liquid and in that the discontinuity has a shape which is such that a fully cavitated core is developed in at least part of standing ring vortex.

15. Fluid medium rotary power conversion means, substantially as hereinbefore described with reference to any one of Figs. 7, 7a to 7d, 8 to 11, 11a, 12, 13 and 16 of the accompanying drawings.

16. Fluid medium rotary power conversion means, substantially as hereinbefore described with reference to Fig. 14 of the accompanying drawings.

17. Fluid medium rotary power conversion means, substantially as hereinbefore described with reference to Fig. 15 of the accompanying drawings.

18. A gas turbine axial flow compressor including fluid medium rotary power conversion means as claimed in any one of claims 1 to 13, 15 and 16.

19. Marine propulsion apparatus including fluid medium rotary power conversion means as claimed in any one of claims 1 to 14, 15 and 17.

20. A centrifugal or mixed flow compressor or fan including fluid medium rotary power conversion means as claimed in any one of claims 1 to 15.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1980.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.